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Repair Techniques for Deteriorated Bridge Substructures

Prepared for
WHRP Structures Technical Oversight Committee

Prepared by
CTC & Associates LLC
WisDOT Research & Library Unit

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Transportation Literature Searches are prepared for WisDOT staff and investigators to identify completed research and other authoritative information in an area of interest. The citations below are representative, rather than exhaustive, of available English-language studies on the topic. Primary online resources for the literature searches are OCLC's WorldCat and TLCat, U.S. DOT's TRIS Online, the National Transportation Library (NTL), TRB's Research in Progress (RiP) database, and other academic, engineering and scientific databases as appropriate.

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Keywords: bridge, pile, repair, rehabilitation, substructure, deterioration.

Summary

We found 16 citations for documents published in 2002 or later, and three Research in Progress entries. One of the citations was published in 2009, one in 2008, five in 2007, two in 2006, four in 2005, and one each in 2004, 2003, and 2002. Two of the 19 citations refer to NCHRP reports. Three citations refer to state DOT studies.

Citations

Links to online copies of cited literature are provided when available. Contact the WisDOT Library to obtain hard copies of citations.

Title: Cathodic Protection for Life Extension of Existing Reinforced Concrete Bridge Elements, NCHRP Synthesis Report
Author(s): Sohanghpurwala, Ali Akbar
Date: 2009
Source/URL: NCHRP Synthesis Report
http://www.trb.org/Publications/Blurbs/Cathodic_Protection_for_Life_Extension_of_Existing_162284.aspx.
Description: 58 pages
Contents: TRB's National Cooperative Highway Research Program (NCHRP) Synthesis 398: Cathodic Protection for Life Extension of Existing Reinforced Concrete Bridge Elements examines the use of cathodic protection by state transportation agencies for controlling corrosion on existing reinforced concrete bridge elements. The report also explores the different types of cathodic protection systems, highlights case studies of states using these systems, and reviews reasons why public agencies may or may not employ cathodic protection.

Title: Bond Enhancement for FRP Pile Repair in Tidal Waters
Author(s): Winters, Danny; Mullins, Gray; Schrader, Andy; Stokes, Michael
Date: May/June 2008
Source/URL: *Journal of Composites for Construction*, Vol. 12, No. 3, pages 334-343.
Description: 10 pages
Contents: Vacuum bagging and pressure bagging are established techniques used by the composites industry for fabricating components. This paper describes a study that explored the adaptation of these techniques for improving the FRP-concrete bond in the repair of partially submerged piles. Prototype vacuum bagging and pressure bagging systems were developed and bond improvement assessed from results of pullout tests on full-size piles repaired under simulated tide in the laboratory. Pressure bagging gave better bond and was found to be simpler because it did not require an airtight seal. A field demonstration project was conducted in which pressure bagging was used in combination with two different GFRP systems to repair two corroding piles supporting the Friendship Trails Bridge across Tampa Bay. Inspection of the postcured wrap showed no evidence of air voids. The study demonstrates that techniques developed by the composites industry may be readily adapted to provide effective and inexpensive means for improving FRP-concrete bond.

Title: Countermeasures to Protect Bridge Piers from Scour
Principal Investigator(s): Lagasse, Peter F.; Clopper, P.E.
Date: 2007
Source/URL: NCHRP Report 593,
http://www.trb.org/Publications/Blurbs/Countermeasures_to_Protect_Bridge_Piers_from_Scour_156796.aspx.
Description: 284 pages
Contents: NCHRP Project 24-07, "Countermeasures to Protect Bridge Piers from Scour," was completed in July 1999. Project 24-07 involved extensive laboratory testing of riprap, cable-tied blocks, grout-filled bags, permeable sheet piles, pier-attached vanes, and submerged vanes. The laboratory testing demonstrated an enhancement in the performance of riprap and cable-tied blocks when used in conjunction with a geotextile filter. Other countermeasures investigated were shown to be less effective in resisting scour. Several countermeasures such as grout-filled mats, gabions, partially grouted riprap, and geotextile sand containers were not investigated. The results of Project 24-07 provided significant insight into the behavior of the tested countermeasures; however, additional research and field validation of countermeasure performance is needed to develop specific countermeasure selection criteria, guidelines, and specifications.

Title: Investigation of Steel-Stringer Bridges: Superstructures and Substructures, Volume I
Author(s): Wipf, Terry J.; Klaiber, Wayne F.; White, David J.; Koskie, Jeremy
Date: October 2007
Source/URL: Report from Iowa Department of Transportation.
Description: 191 pages
Contents: There are hundreds of structurally deficient or functionally obsolete bridges in the state of Iowa. With the majority of these bridges located on rural county roads where there is limited funding available to replace the bridges, diagnostic load testing can be utilized to determine the actual load carrying capacity of the bridge. One particular family or fleet of bridges that has been determined to be desirable for load testing consists of single-span bridges with non-composite, cast-in-place concrete decks, steel stringers, and timber substructures. Six bridges with poor performing superstructure and substructure from the aforementioned family of bridges were selected to be load tested. The six bridges were located on rural roads in five different counties in Iowa: Boone, Carroll, Humboldt, Mahaska, and Marshall. Volume I of this report focuses on evaluating the superstructure for this family of bridges. This volume discusses the behavior characteristics that influence the load carrying capacity of this fleet of bridges. In particular, the live load distribution, partial composite action, and bearing restraint were investigated as potential factors that could influence the bridge ratings. Implementing fleet management practices, the bridges were analyzed to determine if the load test results could be predicted to better analyze previously untested bridges. For this family of bridges it was found that the ratings increased as a result of the load testing demonstrating a greater capacity than determined analytically. Volume II of this report focuses on evaluating the timber substructure for this family of bridges. In this volume, procedures for detecting pile internal decay using nondestructive ultrasonic stress wave techniques, correlating nondestructive ultrasonic stress wave techniques to axial compression tests to estimate deteriorated pile residual strength, and evaluating load distribution through poor performing timber substructure elements by instrumenting and load testing the abutments of the six selected bridges are discussed. Also, in this volume pile repair methods for restoring axial and bending capacities of pile are developed and evaluated.

Title: Investigation of Steel-Stringer Bridges: Substructure and Superstructure, Volume II
Author(s): White, David; Mekkawy, Mohamed; Klaiber, Wayne; Wipf, Terry
Date: October 2007
Source/URL: Report from Iowa Department of Transportation.
Description: 293 pages
Contents: Problems with unknown bridge foundations in Iowa are often associated with timber substructures. Timber piles are subject to biological and physical deterioration, which makes quantifying in-service pile capacity difficult. Currently there are no reliable means to estimate the residual carrying capacity of an in-service deteriorated pile; and thus, the overall safety of the bridge cannot be determined. The lack of reliable evaluation methods can lead to conservative and costly maintenance practices. This research study was undertaken to investigate procedures for assessing bridge substructures, and evaluating procedures for rehabilitating/strengthening/replacing inadequate substructure components. The report includes an extensive literature review, a field reconnaissance study of 49 bridges, a survey of substructures, and finally a laboratory study evaluating selected repair methods.

Title: Fiber-Reinforced Polymer Repair and Strengthening of Structurally Deficient Piles
Author(s): Sen, Rajan; Mullins, Gray; Shahawy, Mohsen
Date: 2007
Source/URL: *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2028/2007, pages 221-230.
Description: 10 pages
Contents: The poor durability of conventional repairs has led to increased interest in the application of fiber-reinforced polymers (FRP) for repairing corroded concrete structures. The availability of resins that can cure under wet conditions has made it possible to consider FRP for repairing partially submerged piles. An overview is provided of a recently completed multiyear study that investigated this problem. In the project, laboratory studies were conducted to determine the effectiveness of FRP in corrosion repair, and two field demonstration projects were completed. A simple, new design method was developed and used for the design of the FRP wrap in the demonstration projects. Some of the issues related to pile repair are addressed, with particular attention to the newly developed design method.

Title: Retrofitting Design and Physical Modeling for Pier-Scour Protection
Author(s): Park, Sang-Kil; Julien, Pierre Y.; Ji, Un; Chang, Tae Rae; Park, Byung Yul
Date: 2007
Source/URL: Conference Proceeding Paper from World Environmental and Water Resources Congress, 2007, pages 1-14.
Description: 14 pages
Contents: The bridge piers of the old Gupo Bridge collapsed during Typhoon Maemi in 2003. Due to the highway construction for the Dadae Harbor in the leftbank side of the Gupo and Subway bridges, the rightbank floodplain should be excavated to ensure the flow full channel area. Bridge piers affected by the excavation are Pier 11 and 12 of the Subway Bridge and Pier 15 and 16 of the Gupo Bridge. The proposed design for the Gupo and Subway Bridge piers is using the sheet pile and riprap to protect the piers. The sheet piles around each pier can be either square or rectangular. Detailed design calculations for the proposed design such as scour depth and scour-hole width around bridge piers, and riprap and filter protections are conducted. Also, the experimental physical modeling is carried out to compare with scour calculation results and to validate the stability of the proposed countermeasure.

Title: CFRP Repair and Strengthening of Structurally Deficient Piles: Design Issues and Field Application
Author(s): Chaallal, Omar; Shahawy, Mohsen; Hassan, Munzer
Date: January 2006
Source/URL: *Journal of Composites for Construction*, Vol. 10, No. 1, pages 26-34.
Description: 9 pages
Contents: The application of carbon fiber reinforced polymers (CFRP) for the repair and strengthening of corrosion-damaged elements is relatively recent. Although several demonstration studies have been completed, no formal design method is available. This paper presents analyses developed for the repair and rehabilitation of four square prestressed piles exposed to an aggressive marine environment. The analysis considers both loss in strength and corrosion-induced expansion. Strength restoration is obtained from interaction relations using a strain compatibility analysis. The longitudinal fibers of the bidirectional FRP layer configuration were designed to restore the strength; whereas, the transverse fibers were verified that they provide the necessary confinement to withstand expansive strains caused by corrosion. Three models proposed by Caltrans, ISIS, and the writers are compared. The Caltrans model is found to be the most conservative. The ISIS and the writers' model gave similar results. A field demonstration was carried out in which segments of four prestressed piles located in the splash zone supporting the

Allen Creek Bridge in Clearwater, Florida, were wrapped. Two of these piles are instrumented for continuous monitoring of their corrosion performance.

Title: Application of FRP Composites for Underwater Piles Repair
Author(s): Sen, Rajan; Mullins, Gray
Date: March 2006
Source/URL: University Paper from University of South Florida, http://www.quakewrap.com/frp%20papers/Application-of-FRP-Composites-for-Underwater-Piles-Repair.pdf.
Description: N/A
Contents: The lightweight, high strength and corrosion resistance of fiber reinforced polymers (FRP) make them ideally suited for quick and effective structural repairs. As a result, they have been favoured for conducting emergency bridge repairs where speed is of essence. The availability of resins that can cure under water has made it possible to similarly extend its application to substructure elements such as partially submerged damaged piles. Such repairs can be carried out using the same strategies that were successfully used in recent demonstration projects in which FRP was used to repair and rehabilitate corrosion-damaged piles. In the projects two disparate FRP systems—a pre-preg and a wet layup—were used and both carbon and glass evaluated. Access to the piles in the deep waters was provided by a custom-designed, lightweight modular scaffolding system that was assembled around the piles. An overview of the project is provided with particular emphasis on changes that would allow its adoption for emergency repairs.

Title: Durable Repairs on Marine Bridge Piles
Author(s): Thaesler, Patricia; Oberle, Rita; Demers, Cornelia E.
Date: February 2005
Source/URL: *Journal of Performance of Constructed Facilities*, Vol. 19 No. 1, pages 88-92.
Description: 5 pages
Contents: Durable repairs of bridge piles exposed to a marine environment require a proper repair design, which includes understanding and preventing the deterioration mechanism in such environments and proper construction methods. To understand how repair systems work, it is important to recognize which deterioration mechanism the system prevents and controls. Conversely, to understand why a system does not work, one must determine the deterioration mechanisms that the system failed to control. The deterioration mechanism should be addressed before repair construction starts so that an appropriate solution can be achieved. Also, construction practices that accelerate deterioration mechanisms should be recognized and avoided. This paper describes efficient construction methods that can be incorporated in the construction of bridge pile repairs. It also gives recommendations to increase the life of a bridge pile repair by analyzing deterioration of repaired structures, defining the cause of deterioration, providing suggestions to enhance the performance of the repair by practical and feasible actions, and giving an integrated approach to bridge repair construction processes.

Title: Bridge Scour and Substructure Deterioration: Case Study
Author(s): Avent, R. Richard; Alawady, Mohamed
Date: May/June 2005
Source/URL: *Journal of Bridge Engineering*, Vol. 10, No. 3, pages 247-254.
Description: 8 pages
Contents: In 1988, the State of Mississippi set up its first statewide underwater bridge inspection program. During this inspection, serious damage was found on the substructure of two parallel bridges on I-10 near Biloxi. Significant scour had occurred, exposing the steel piling. These piles had severe corrosion with cross sections reduced by 50 percent. Because of the reduced cross section, the web and flanges of the piles had buckled locally. This damage was exacerbated by collisions associated with barge traffic on the waterway. This accumulation of problems resulted in a bridge on the verge of collapse. Two alternatives were used to repair the substructure. The more seriously damaged piles were encased in concrete, and the less seriously damaged ones were dewatered and a concrete seal was placed around the piles. After 10 years, the piers with pile encasements showed no additional scour effects. However, the piers with the large concrete seals had scoured by as much as 3 m (10 ft.). Described in this paper is the analysis of damage, design of the repair, and a review of the performance of the two types of repair over a 10-year period.

Title: Underwater Fiber-Reinforced Polymers Repair of Prestressed Piles in the Allen Creek Bridge
Author(s): Mullins, Gray; Sen, Rajan; Suh, Kwangsuk; Winters, Danny
Date: March/April 2005
Source/URL: *Journal of Composites for Construction*, Vol. 9, No. 2, pages 136-146.
Description: 11 pages
Contents: This paper presents an overview of a demonstration project in which corroding prestressed piles located in tidal waters were wrapped underwater using carbon and glass fiber-reinforced polymer material. An innovative instrumentation scheme was developed to allow assessment of the prewrap and postwrap corrosion state using linear polarization. This system is simple to install and eliminates the need for wiring or junction boxes. The underwater wrap used a unique water-activated urethane resin system that eliminated the need for cofferdam construction. Linear polarization measurements taken before and after wrapping indicate that the corrosion rate in the wrapped specimens is consistently lower than those in its unwrapped counterpart. These preliminary findings are encouraging and suggest that underwater wrapping without cofferdam construction may provide a cost-effective solution for pile repair.

Title: Inspection, Repair and Rehabilitation of Concrete Structures Due to Corrosion
Author(s): Hyman, Alan E.
Date: 2005
Source/URL: *International Journal of Materials and Product Technology*, Vol. 23, No. 3/4, pages 309-337.
Description: 18 pages
Contents: The state of Florida (United States) is located in an extremely aggressive environment. The long coast line has many causeway bridges and box culverts where salt water intrusion in concrete structures has been well documented by the bridge inspection process. All bridges that have an opening measured along the center of the roadway of more than 6.0 m (20 ft.) are inspected at regular intervals not exceeding two years. The bridge inspection reports document the signs that corrosion has begun such as rust staining, efflorescence, cracking and spalling. This paper describes some of these bridge repair projects that have been undertaken by the Florida Department of Transportation in the past few years, how each individual project was developed, how it is currently performing, and measures to prevent corrosion from occurring in future structures. Specific topics include how the concrete corrosion begins, the use of pile jackets and cathodic protection, the effect of carbon fiber-reinforced polymer (CFRP) concrete, joint repair, and full-depth deck repair.

Title: Composites Cut Costs of Repairing Corrosion-Prone Systems
Author(s): Pottish, Nancy
Date: December 2004
Source/URL: *Composites Technology*, Vol. 10, No. 6, pages 38-41.
Description: 4 pages
Contents: Composites are increasingly being used in corrosion repair, particularly in refinery pipelines that must withstand highly corrosive byproducts of oil production, and in fortification of bridge pilings damaged by corrosion of internal rebar reinforcements. This article examines the composite materials and methods used for repairs in case studies from each field. The unique technical and regulatory challenges encountered by composite repair specialists in each case are highlighted. In the first case, a steel flare line at an oil refinery in Tennessee was repaired with a glass-reinforced composite wrap process. In the second case, a footbridge over Tampa Bay in Florida is being used as a test site to gauge the effectiveness of composite wrapping to treat corrosion in the bridge's piles. Eight of the piles are involved in the study—two are unwrapped and serving as controls, four are wrapped with a water-activated polyurethane prepreg system, and two are wrapped with an epoxy wet layup system. A cathodic protection system was incorporated into one of the piles. Several of the piles have been instrumented with probes to read current flow between the top of each pile and the middle section to measure whether the wraps are successfully slowing or stopping the corrosion process.

Title: Minimizing the Impact on Water Quality of Placing Grout Underwater to Repair Bridge Scour Damage
Author(s): Fitch, Michael G.
Date: March 2003
Source/URL: Report from Virginia Department of Transportation, http://www.virginiadot.org/vtrc/main/online%5Freports/pdf/03-r16.pdf.
Description: 31 pages
Contents: The Virginia Department of Transportation (VDOT) has routinely used what is commonly referred to as tremie concrete (concrete or grout placed underwater by way of pumping through a metal tremie pipe) to repair bridge substructure and scour damage. VDOT also recently began to place concrete underwater to repair scour by

pumping it directly into grout bags. Many of VDOT's rehabilitation projects that involve underwater concrete placement require environmental permits that VDOT's Environmental Division is responsible for securing from various regulatory agencies. Because the effects of tremie concrete on water quality have been a concern for some of these agencies, namely the Virginia Department of Environmental Quality and the U.S. Army Corps of Engineers, the acquisition of these permits has become a problem. As a consequence, the agencies put a number of VDOT projects on hold until the problems with tremie concrete were better documented and/or until VDOT developed a better method of repairing bridge scour. The Department of Environmental Quality requested that all in-stream scour repairs, with few exceptions, be conducted "in the dry." The purpose of this study was to determine a way to allow VDOT to remain in compliance with current state and federal water quality standards and regulations while rehabilitating structures with significant scour using concrete placed underwater. The study included the monitoring of 31 sites in the field and a laboratory component to compare the effects of various placement methods on various water quality parameters. Results showed that the primary water quality parameter affected by the placement of grout underwater is pH. Such placement can cause pH values to exceed 11 under particular flow conditions. However, in-stream pH values can be kept below the state water quality level of 9.0 through the use of a combination of placement techniques and/or an anti-washout admixture. The techniques required are very site-specific but depend primarily on stream flow volume and grout pumping rates.

Title: Zinc-Mesh Jacket System Improves Corrosion Control
Author(s): Leng, D. L.
Date: November 2002
Source/URL: *Better Roads*, Vol. 72, No. 11, pages 34-40.
Description: 7 pages
Contents: A severely corroded bridge in Florida is given new life by encasing its pilings with a zinc jacket called a Lifejacket Cathodic Protection System. It is composed of zinc mesh and a fiberglass form and is used for decay caused by chloride-induced corrosion. The jacket produces a galvanic cell that creates enough electrical current to prevent further corrosion of embedded steel. Cathodic protection is the only technique proven to stop corrosion in salt-contaminated materials. The galvanic approach is self-correcting and needs little maintenance versus the other method, impressed-current systems, which need continuous adjustments to respond to changing environmental conditions. Gives detailed explanation of the Florida installation, including photos and figures illustrating the mechanics of the system. The cost compares well with standard pile jacketing and grows more economical over time.

Research in Progress

Title: Underwater Fiber-Reinforced Polymer Repair of Corroding Piles Incorporating Cathodic Protection
Principal Investigator(s): Jawed, Inam (Project Manager), IJAWED@nas.edu
Start Date: August 2008
RIP URL: http://rip.trb.org/browse/dproject.asp?n=18975
Sponsor Organization: NCHRP Highway IDEA Program
Contents: Cathodic protection is a proven method to stop corrosion in chloride-contaminated concrete. On the other hand, the lightweight, high strength, and corrosion resistance of fiber-reinforced polymer (FRP) make it the ideal repair material. This study incorporates cathodic protection within a bonded FRP repair to develop a new system that takes advantage of both technologies. The efficacy of the proposed system is contingent on the integrity of the FRP-concrete bond. Bond is known to be enhanced by the application of sustained pressure. Thus, in segmental construction, a minimum compressive pressure of 276 kPa (40 psi) is applied to join epoxied match-cast units. If uniform pressure can be similarly maintained on the FRP wrap while the resin cures, the FRP-concrete bond may be expected to improve.

Title: Efficient Repair of CIDH Bridge Foundations: Phase 1—Effectiveness of Water Jetting for Removal of Anomalies
Principal Investigator(s): Fiegel, Gregg, California Polytechnic State University, gfiegel@calpoly.edu
Start Date: June 2008
RIP URL: http://rip.trb.org/browse/dproject.asp?n=22916
Sponsor Organization: California Department of Transportation
Contents: What is the most efficient and effective means of repairing defects in Bridge Foundation Piles? The first phase of this task specifically investigates water jetting as part of grouting repairs for Cast-in-Drilled Hole (CIDH) Piles. Phase I seeks to answer: How effective is high-pressure water jetting to remove competent concrete, anomalous concrete, and concrete that is contaminated with soil or foreign matter? Bridge Foundations, especially CIDH piles installed under slurry, are highly loaded critical structural elements constructed under very adverse conditions. Naturally, these elements are very likely to contain defects that necessitate repair in the field. Methods employed for repair are often unverified solutions based upon past practice, and recent investigations has shown that some previously accepted practices were much less effective in mitigating defects than believed. The question emerges, what methods of repair are both efficient and effective to repair these defects? To answer this question, this research task is conducted in four phases so that the information gathered in each phase will be rapidly incorporated into practice. The research phases are: Phase-I: Water Jetting of CIDH Pile Anomalies in the Laboratory, Phase-II: Effectiveness of Permeation Grouting Method for CIDH Pile Repair, Phase-III: Analysis of Innovative (non-grouting) Repair Techniques for CIDH Pile Mitigation, Phase-IV: Post-Repair Evaluation Methods. Phase I limits itself to answering the first part of this multifaceted question. Since grouting repair is the most common repair method currently, and water jetting is the first step in this process, how effective is water jetting? Future phases of this project will investigate other aspects of grouting repairs and the effectiveness of other means utilized by the contractor.

Title: District 3-0 Investigation of Fiber Wrap Technology for Bridge Repair and Rehabilitation
Principal Investigator(s): Davalos, Julio F., West Virginia University
Start Date: January 2008
RIP URL: http://rip.trb.org/browse/dproject.asp?n=22492
Sponsor Organization: Pennsylvania Department of Transportation
Contents: The technical and cost-effective application of externally bonded Fiber Reinforced Polymer (FRP) for the repair and rehabilitation of concrete bridges is well established and documented. Based upon this and previous District 3-0 studies, the repair of concrete T-beam bridge no. 49-4012-0250-1032, using Carbon Fiber-Reinforced Polymer (CFRP) fabrics, has been designed and plans have been prepared for the bridge to be rehabilitated by contract. The objective of this project is to assist District 3-0 with this rehabilitation project, by utilizing existing accepted practices and documenting the applicability of FRP technology specifically for concrete T-beam bridge repair by the Pennsylvania Department of Transportation (PennDOT). Additionally, the outcomes of this project will be to develop design and construction guidelines for the effective and economical structural repair of concrete T-beam bridges. These guidelines will subsequently be used as standards for future PennDOT projects. The work order under this agreement will allow for the oversight of contract repairs, concurrent and follow-up laboratory and field tests to validate design and construction methodologies utilized, assist with and evaluate quality control (QC) procedures for materials and workmanship, perform structural and cost analyses of the repaired bridge, evaluate the expected long-term performance of the FRP-repair technology through lab-scale tests and analyses, and develop guidelines for use on future PennDOT repair/rehabilitation projects in the district and statewide.